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EFFECTS OF CERTAIN ALKALI SALTS ON AMMONIFICATION

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Effects of Certain Alkali Salts on Ammonification

By P. E. BROWN AND D. R. JOHNSON

The occurrence of so-called "alkali spots" in certain Iowa soils has been noted in recent publications (1), (7). These spots are found only in the Wisconsin drift soil area, in association with peat deposits, and are the result of course of peculiarly poor drainage conditions. It is unnecessary here to consider further the causes of these formations or the methods which should be followed in reclaiming the areas affected as these points have been discussed in the publications referred to. It will be sufficient to call attention to the results of the chemical studies of the spots and to consider briefly some of the conclusions which were reached in those studies.

Many samples of soil from areas where crop injury was noticed were analyzed and small amounts of various "alkali" salts were found. The same salt was not present in all cases, however, and in fact, great diversity occurred among the different samples. Sulfates, carbonates, bicarbonates, chlorides and nitrates of sodium, magnesium and calcium were occasionally found but the amount of any "alkali" salt present was never sufficiently large to account for crop injury.

Examinations of the spots in the field during periods of drouth showed heavy incrustations of white, yellowish, or even brownish-white salts. Analyses of various samples of these efflorescences were made and it was found that they were very largely composed of calcium carbonate. This salt was likewise found to be present in large amounts in all the soils where "alkali spots" occurred. It is evident, therefore, that the soil solution in such soils must be heavily loaded with calcium bicarbonate for it is well known that this salt is formed in soil water from calcium carbonate and when the soil dries out, the bicarbonate is carried up to the surface in the capillary moisture and deposited as the carbonate.

In consideration of all these facts, several possible explanations of the injurious factor in the "alkali spots" suggest themselves. In the first place, while the amounts of "alkali" salts present are too small to be injurious, it is possible that when present with large amounts of calcium bicarbonate in the soil water,

or, in other words, in a highly concentrated soil solution, they may prove distinctly toxic. In the second place, the high concentration of salts in the soil water may account for the difficulty, regardless of the kind of salts present. Finally, it is possible that calcium bicarbonate when present in excessive amounts in the soil solution may become harmful to crop growth.

Bacterial activities in soils are apparently rather closely allied with crop production and if small amounts of "alkali" salts in the presence of calcium carbonate, heavy concentrations of salts in the soil solution, or excessive amounts of calcium bicarbonate, reduce such processes as ammonification, nitrification, etc., which reflect available plant food production, a decreased crop growth may result.

The study of the problem from the bacteriological standpoint may be of value not only in indicating the causes of the injurious effect of the "alkali" spots, but also in leading to methods of reclamation.

With these facts in mind, the object of the work reported in the following pages was to study the effect of certain so-called "alkali" salts on ammonification in the presence and in the absence of calcium carbonate. Varying quantities of several salts were used and the attempt was made to determine the concentration at which each became toxic to the ammonifiers. It was also desired to ascertain whether the presence of extremely large amounts of calcium carbonate would alter the toxic concentrations of the various salts. The question of the toxicity of calcium carbonate when present alone in excessive quantities was likewise considered.

The results secured in this work are presented at the present time for their technical interest and as a step toward the solution of the large problem. They should not therefore be interpreted too broadly. Much further work must be done and particularly is it necessary that extensive tests along these lines with various crops be carried out before conclusions of practical significance should be drawn.

HISTORICAL.

Many experiments have been conducted on the effects of calcium carbonate on ammonification and these have quite uniformly shown this material to be beneficial when used in normal amounts. With excessive applications, however, a few instances of injurious action have been noted. It is unnecessary to summarize the experiments along this line as excellent bibliographies of references have been given in other publications.

The effects of "alkali" salts on ammonification have been studied to only a limited extent. The work of C. B. Lipman (4) constitutes the only series of experiments which bears directly on the present problem. He studied the toxic effects of sodium chloride, sodium sulfate and sodium carbonate. Ammonification in soils was inhibited by the presence of various amounts of each of the salts used. The chloride was found to be the most toxic, the sulfate less so and the carbonate was only slightly toxic, except at very high concentrations. The actual points at which these salts became markedly toxic to ammonification were between 0.1% and 0.2% for NaCl , 0.4% for Na_2SO_4 and 2.0% for Na_2CO_3 . These salt effects were very different from those noted on plants by the alkali salts mentioned. In fact, the conditions were about reversed. In a more recent publication Lipman (5) observed a less harmful effect of these salts on ammonification when used in the presence of one another than when used alone. He found that sodium carbonate and sodium chloride together were less toxic to ammonification than sodium carbonate alone or sodium chloride alone. This same action was noted for all combinations of salts tested. The cause of these differences is attributed to an antagonism set up by the anions of the salts used in combination.

Other experiments have dealt with the effects of "alkali" salts on nitrification but these have been reviewed in another publication (2) and will therefore not be considered here.

The experiments of Brown and Hitchcock (2), altho dealing with nitrification also consider the effects of "alkali" salts in the presence of calcium carbonate. Their experiments show that nitrification in normal soil is stimulated by small amounts of NaCl , Na_2SO_4 , MgSO_4 and large amounts of CaCO_3 . These salts became toxic, however, at 0.02% NaCl , 2.00% Na_2SO_4 and between 1.5% and 6.0% CaCO_3 . Nitrification in alkali soil was increased by small amounts of NaHCO_3 , Na_2CO_3 and CaCO_3 . CaSO_4 had no effect, Na_2CO_3 and NaHCO_3 became toxic at 0.3% and CaCO_3 at 6.0%. CaSO_4 added with the sodium carbonate and bicarbonate in the proper amount to react with them prevented any toxic action from the largest amount used. Greenhouse tests confirmed in general the laboratory results. Crop yields were affected by the salts used similarly to nitrification.

Greaves (3) in some recent studies on the influence of salts on soil bacteria found that the toxicity of various salts as determined by ammonification was controlled largely by the electro-negative ion and as a general rule, to which there were exceptions, the chlorides were the most toxic, and nitrates, sulfates,

and carbonates followed in the order of decreasing toxicity. The quantity of a salt which could be applied to a soil without decreasing ammonia varied with the salt, the salts tested being listed in the order of their toxicity in the soil studied. He found that the toxicity of some salts increased more rapidly than that of others. The increased osmotic pressure exerted by the salt added to the soil played a great part in retarding bacterial activity, but it was not the only factor.

The main factor is believed to be a physiological one, due to the action of the salt on the living protoplasm of the cell.

The common soil "alkalis" were found to be very toxic to ammonification. With some exceptions, the salts used acted as stimulants on ammonification at some concentration, the extent of stimulation and quantity of salt producing maximum stimulating varying widely. The same compounds which are most active in stimulating higher plants were found also to be most active in stimulating bacteria. The quantity of certain salts necessary to reduce the ammonifying power of the soil to half normal was found to be practically the same as the quantity necessary to reduce the growth of wheat to the same extent. With most salts, however, the ammonifiers seemed to be more resistant than the higher plants.

No other experiments of application along this line are available at the present time.

EXPERIMENTAL.—PART I.

LABORATORY EXPERIMENTS.

Part I of the experimental work here reported deals with the laboratory experiments and Part II, with the greenhouse tests. The same soil was used throughout the work so that the results are all comparable. It is known as Carrington loam and is a dark brown to black loam on yellow clay loam.

The experiments of Part I were arranged in series for convenience in manipulation. Variations in the results from the same soils may be attributed to differences in the temperature of incubation or to slight differences in the incubation period. A large sample of soil was secured, air-dried, sieved and stored for use. The tests were carried out in 100 gm. portions of the soil weighed out in tumblers. Five gms. of dried blood were added to each portion of soil and thoroughly stirred in. Additions of salts were then made as desired, 10 c. c. of an infusion of a fresh soil introduced and the moisture content adjusted at the optimum

for the soil. The tumblers were covered and incubated for six days at room temperature. The ammonia present was then determined by the aeration method of Potter and Snyder (6).

SERIES I.

This series was planned to determine the effect of large amounts of calcium carbonate on ammonification in this soil. The plan of the experiment and also the results secured appear in the following table.

It is evident from table I that the small application of calcium carbonate was extremely beneficial to the ammonifying bacteria. Over twice as much ammonia was produced as in the untreated soil. Larger applications, however, beyond this three ton amount did not bring about any further increase in ammonification. These results confirmed very satisfactorily previous work along this line.

Even when the applications of lime became excessive, there was no decrease in ammonification, the production of ammonia remaining about the same with the fifty ton application as with the smaller amounts.

It now remained to ascertain the effect of varying quantities of certain salts on the ammonifying bacteria in this soil in the presence and absence of calcium carbonate. If the salts had the same effects whether or not lime was present in large amount, then it might be concluded that the excess of calcium carbonate which distinguishes the "alkali" spots would not be of importance in determining the injurious factor, at least as far as the ammonifying bacteria were concerned. On the other hand, if amounts of salts non-toxic in the absence of lime became in-

TABLE I.—THE EFFECTS OF CALCIUM CARBONATE ON AMMONIFICATION.

No.	Treatment	Mg N as Ammonia	Average
1	Check	74.3687	
2	Check	70.7221	72.557
3	0.3 gm CaCO_3	163.7201	
4	0.3 gm CaCO_3	175.6011	169.665
5	0.6 gm CaCO_3	171.5101	
6	0.6 gm CaCO_3	159.4001	165.500
7	1.0 gm CaCO_3	160.2201	
8	1.0 gm CaCO_3	163.3501	163.286
9	2.5 gm CaCO_3	162.7101	
10	2.5 gm CaCO_3	157.1111	164.960
11	5.0 gm CaCO_3	170.6137	
12	5.0 gm CaCO_3	166.5871	168.756

jurious in its presence, it would be evident that the content of calcium carbonate in the spots was of prime importance.

SERIES II.

This series showed the effects of varying amounts of sodium carbonate on ammonification. The plan of the test and the results appear in table II.

Referring to the above data, it will be seen that sodium carbonate used in a concentration of 0.1 per cent had a stimulating influence on the ammonifying power of the soil. When the concentration was increased to 0.2% a distinct depression in ammonification over that in the check soil was noted. Further increases in the salt addition brought about still greater decreases in ammonification until with 1% less than half as much ammonia was produced as in the check soil. The toxic point for sodium carbonate in this soil therefore, was between 0.1 and 0.2%. These results were quite different from those secured by Lipman. In his experiments sodium carbonate was beneficial up to 1% and became toxic only beyond that point. The point of marked toxicity he placed at 2.0%. The differences in his results from those secured in this experiment are undoubtedly due to the different soils used in the experiments. Salt effects are undoubtedly different in soils of varying physical and chemical composition and these results show that fact quite distinctly. An amount of salt injurious to ammonification in one soil will not necessarily be injurious in other soils. The same fact may be true in the case of crops. Experiments along this line are lacking at the present time.

TABLE II.—THE EFFECTS OF SODIUM CARBONATE ON AMMONIFICATION.

No.	Treatment	Mg N as Ammonia	Average
1	Check	39.92	42.135
2	Check	44.35	
3	0.1 gm Na_2CO_3	45.60	46.115
4	0.1 gm Na_2CO_3	52.63	
5	0.2 gm Na_2CO_3	36.66	33.010
6	0.2 gm Na_2CO_3	29.42	
7	0.5 gm Na_2CO_3	31.05	25.515
8	0.5 gm Na_2CO_3	19.98	
9	1.0 gm Na_2CO_3	17.55	16.745
10	1.0 gm Na_2CO_3	15.94	

SERIES III.

This series was arranged to show the effect of sodium carbonate when used in combination with calcium carbonate. The concentration of calcium carbonate remained constant at 0.6% while the amounts of salt were varied. The various treatments and results are given in table III.

The results of this series and of the preceding are shown graphically in plate I.

Table III and plate I show 0.1% of sodium carbonate in the presence of calcium carbonate gave practically no beneficial or injurious effect. The same is true of the 0.2% application although a slight depression was noted in the latter case. Beyond that amount, however, gradually decreasing amounts of ammonia were produced. The sodium carbonate evidently was very much less toxic to ammonification in the presence of a large amount of calcium carbonate than in the absence of the latter. Calcium carbonate apparently was able to remove or neutralize the toxicity of sodium carbonate to some extent. Instead of small amounts of this salt becoming more toxic in the presence of calcium carbonate, the reverse was the case and the toxicity of several amounts of the salts was removed or at least considerably reduced by calcium carbonate.

With the smallest amount of sodium carbonate however which, when used alone, proved beneficial to ammonification, the addition of calcium carbonate reduced the beneficial influence. There are indications here that with small stimulative or non-toxic amounts of the sodium bicarbonate, calcium carbonate may reduce the stimulative influence, but with toxic amounts of the salt the calcium carbonate apparently reduces the toxicity. Evidently the influence of lime in "alkali" spots is, therefore, quite dif-

TABLE III.—THE EFFECTS OF SODIUM CARBONATE IN THE PRESENCE OF CALCIUM CARBONATE.

No.	Treatment	Mg N	Average
1	0.6 gm CaCO_3	41.25)	44.875
2	0.6 gm CaCO_3	48.50 (
3	0.1 gm Na_2CO_3 +0.6 gm CaCO_3	42.10)	45.050
4	0.1 gm Na_2CO_3 +0.6 gm CaCO_3	48.00 (
5	0.2 gm Na_2CO_3 +0.6 gm CaCO_3	45.70)	43.100
6	0.2 gm Na_2CO_3 +0.6 gm CaCO_3	40.50 (
7	0.5 gm Na_2CO_3 +0.6 gm CaCO_3	40.40)	39.500
8	0.5 gm Na_2CO_3 +0.6 gm CaCO_3	38.60 (
9	1.0 gm Na_2CO_3 +0.6 gm CaCO_3	30.00)	27.275
10	1.0 gm Na_2CO_3 +0.6 gm CaCO_3	24.55 (

ferent in the presence of different amounts of the "alkali" salt, sodium carbonate.

SERIES IV.

This series was planned to test the effects of sodium bicarbonate on ammonification. The results appear in table IV.

Table IV shows that the small amounts of the bicarbonate were markedly stimulating to the ammonifiers. Beyond 0.05% however, or somewhere between that percent and 0.1%, the salt became toxic. With increasing additions of the bicarbonate further decreases in ammonification occurred until with 5.0% there was very little production of ammonia. This salt was evidently toxic to ammonification in this soil at a lower concentration than was the case with the corresponding carbonate.

SERIES V.

This series was arranged similar to Series III, a fixed amount of calcium carbonate being used and the addition of the sodium bicarbonate varying. The results of these tests appear in Table V.

The results in this table, together with those secured in the preceding series, are shown graphically in plate II. A comparison of this plate with plate I reveals the fact that the curves are very similar, although it must be kept in mind that a smaller amount of the sodium bicarbonate was used and the injurious

TABLE IV.—THE EFFECTS OF SODIUM BICARBONATE ON AMMONIFICATION.

No.	Treatment	Mg N	Average
1	Check	30.38	32.740
2	Check	35.10	
3	0.05 gm NaHCO ₃	43.41	
4	0.05 gm NaHCO ₃	42.90	43.155
5	0.1 gm NaHCO ₃	22.15	
6	0.1 gm NaHCO ₃	27.55	
7	0.2 gm NaHCO ₃	26.45	24.850
8	0.2 gm NaHCO ₃	19.70	
9	0.5 gm NaHCO ₃	12.95	
10	0.5 gm NaHCO ₃	19.98	16.465
11	1.0 gm NaHCO ₃	12.06	
12	1.0 gm NaHCO ₃	7.82	
13	5.0 gm NaHCO ₃	2.43	10.390
14	5.0 gm NaHCO ₃	4.32	

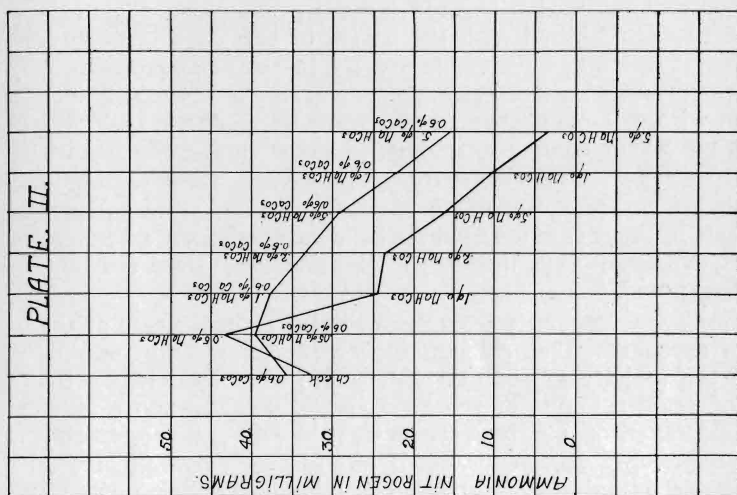


PLATE II. Graph showing effects of sodium bicarbonate on ammonification and effects of sodium bicarbonate in the presence of calcium carbonate.

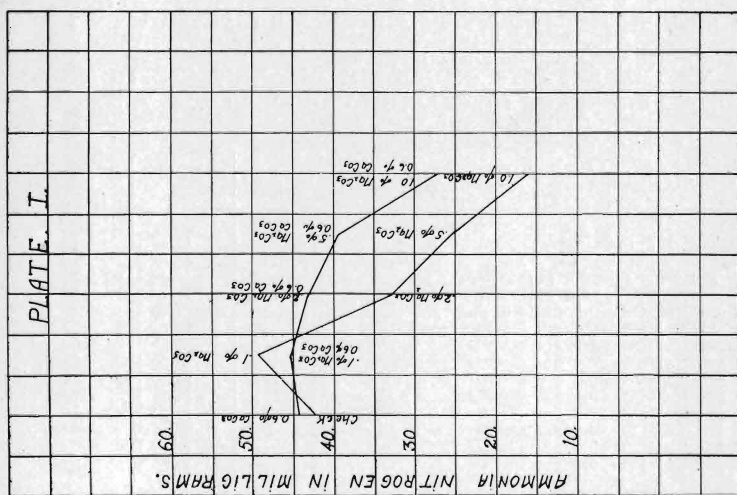


PLATE I. Graph showing effects of sodium carbonate on ammonification and effects of sodium carbonate in the presence of calcium carbonate.

action on ammonification was much more pronounced. The calcium carbonate applied with the 0.05% of sodium bicarbonate, the amount which alone causes a decided increase in ammonification brought about a small effect. An increase over the ammonification with calcium carbonate alone was noted however. These results were very similar to those with the sodium carbonate although they were somewhat more distinctive.

With the larger applications of the bicarbonate the calcium carbonate in every case lessened the injurious action considerably. In fact, with the 0.1% amount, a slight increase over the lime alone was noted.

Again, it was apparent from these results, as in the case of the sodium carbonate, that calcium carbonate can remove or neutralize the toxicity of sodium bicarbonate to some extent. Instead of small amounts of the bicarbonate becoming more toxic with calcium carbonate, the reverse was the case and the toxicity was considerably lessened. Small stimulative amounts of the bicarbonate were, however, reduced in stimulative action on ammonification by the lime. Again it appears that the effects of calcium carbonate in the presence of "alkali" salts depended on the amounts of those salts which were present.

It will be seen from table VI that the small application of the sulfate stimulated the action of the ammonifiers to a con-

SERIES VI.

The effects of sodium sulfate were studied in this series and the treatments made and results secured are given in table VI.

TABLE V.—THE EFFECTS OF SODIUM BICARBONATE IN THE PRESENCE OF CALCIUM CARBONATE.

No.	Treatment	Mg N	Average
1	Check+0.6 gm CaCO_3	37.50	36.440
2	Check+0.6 gm CaCO_3	35.38	
3	0.05 gm NaHCO_3 +0.6 gm CaCO_3	46.18	42.190
4	0.05 gm NaHCO_3 +0.6 gm CaCO_3	38.20	
5	0.1 gm NaHCO_3 +0.6 gm CaCO_3	43.20	37.985
6	0.1 gm NaHCO_3 +0.6 gm CaCO_3	32.67	
7	0.2 gm NaHCO_3 +0.6 gm CaCO_3	32.67	33.885
8	0.2 gm NaHCO_3 +0.6 gm CaCO_3	35.10	
9	0.5 gm NaHCO_3 +0.6 gm CaCO_3	24.30	29.330
10	0.5 gm NaHCO_3 +0.6 gm CaCO_3	34.30	
11	1.0 gm NaHCO_3 +0.6 gm CaCO_3	19.97	22.135
12	1.0 gm NaHCO_3 +0.6 gm CaCO_3	24.30	
13	5.0 gm NaHCO_3 +0.6 gm CaCO_3	17.55	15.390
14	5.0 gm NaHCO_3 +0.6 gm CaCO_3	13.23	

siderable extent. Beyond 0.1% however, or somewhere between 0.1% and 0.5% the sodium sulfate became toxic for with the latter amount a distinct depression in ammonification occurred. With larger amounts still further decreases occurred until with 5.0% the ammonifying action was very slight.

These results agreed very well with those of Lipman who found the toxic point for sodium sulfate at 0.4%. In his results, however, ammonification had practically ceased with 2.0% while in these experiments it was still apparent at 5.0%. Again it appears that the effects of "alkali" salts on ammonification vary with different soils and a concentration of a salt toxic in one soil may not necessarily be so in another soil.

SERIES VII.

This series was arranged to learn the effects of sodium sulfate in the presence of calcium carbonate. The results are given in table VII.

The results in this series and in the preceding are shown together in the curves in plate III.

Examining this plate and table VII, it is evident that in the presence of calcium carbonate, sodium sulfate did not become toxic to ammonification until more than 0.75% was added. Beyond that amount, however, a toxic effect was noted. The smaller amounts of the sulfate with calcium carbonate increased ammonification to a considerable extent, the largest increase occurring with the 0.1% and the 0.5% additions. The increase with the 0.1% amount was greater than where the sulfate was used alone and in the case of the 0.5% amount a depression

TABLE VI.—THE EFFECTS OF SODIUM SULFATE ON AMMONIFICATION.

No.	Treatment	Mg N	Average
1	Check	43.991	
2	Check	52.677	48.334
3	0.1 gm Na ₂ SO ₄	59.962	
4	0.1 gm Na ₂ SO ₄	62.764	61.363
5	0.5 gm Na ₂ SO ₄	39.508	
6	0.5 gm Na ₂ SO ₄	30.822	35.165
7	0.75 gm Na ₂ SO ₄	27.740	
8	0.75 gm Na ₂ SO ₄	18.213	22.976
9	1.00 gm Na ₂ SO ₄	17.682	
10	1.00 gm Na ₂ SO ₄	17.792	17.862
11	5.00 gm Na ₂ SO ₄	2.745	
12	5.00 gm Na ₂ SO ₄	1.401	2.073

TABLE VII.—THE EFFECTS OF SODIUM SULFATE IN THE PRESENCE OF CALCIUM CARBONATE.

No.	Treatment	Mg N	Average
1	Check+0.6 gm CaCO ₃ -----	61.56 }	61.56
2	Check+0.6 gm CaCO ₃ -----	74.52 }	
3	0.1 gm Na ₂ SO ₄ +0.6 gm CaCO ₃ -----	74.52 }	70.06
4	0.1 gm Na ₂ SO ₄ +0.6 gm CaCO ₃ -----	65.60 }	
5	0.5 gm Na ₂ SO ₄ +0.6 gm CaCO ₃ -----	72.80 }	70.00
6	0.5 gm Na ₂ SO ₄ +0.6 gm CaCO ₃ -----	67.20 }	
7	0.75 gm Na ₂ SO ₄ +0.6 gm CaCO ₃ -----	66.98 }	63.59
8	0.75 gm Na ₂ SO ₄ +0.6 gm CaCO ₃ -----	60.20 }	
9	1.00 gm Na ₂ SO ₄ +0.6 gm CaCO ₃ -----	52.60 }	53.30
10	1.00 gm Na ₂ SO ₄ +0.6 gm CaCO ₃ -----	54.00 }	
11	5.00 gm Na ₂ SO ₄ +0.6 gm CaCO ₃ -----	17.28 }	16.47
12	5.00 gm Na ₂ SO ₄ +0.6 gm CaCO ₃ -----	15.66 }	

where the salt was used alone was changed to an increase when calcium carbonate was added.

It is apparent from these results that calcium carbonate reduced the toxic effects of sodium sulfate and in the presence of small, slightly toxic amounts of the salt, it not only offset the injurious action but brought about a beneficial effect. This corresponded in part with the results secured with the sodium carbonate and the sodium bicarbonate. Just as in those cases calcium carbonate reduced the toxicity of the "alkali" salt. With stimulative amounts of the sulfate, however, the calcium carbonate increased the stimulation instead of decreasing it as was the case with the carbonate and bicarbonate.

SERIES VIII.

This series was planned to test the effect of sodium chloride on ammonification. The results are given in table VIII.

TABLE VIII.—THE EFFECTS OF SODIUM CHLORIDE ON AMMONIFICATION.

No.	Treatment	Mg N	Average
1	Nothing -----	76.774 }	75.373
2	Nothing -----	73.792 }	
3	0.005 gm NaCl -----	81.062 }	84.522
4	0.005 gm NaCl -----	87.982 }	
5	0.01 gm NaCl -----	61.924 }	72.571
6	0.01 gm NaCl -----	83.219 }	
7	0.02 gm NaCl -----	73.692 }	69.909
8	0.02 gm NaCl -----	66.127 }	
9	0.05 gm NaCl -----	65.847 }	63.325
10	0.05 gm NaCl -----	60.803 }	
11	0.10 gm NaCl -----	67.160 }	60.943
12	0.10 gm NaCl -----	64.726 }	

It is apparent from table VIII that .005% of sodium chloride stimulated the activities of the ammonifying bacteria. Larger amounts, however, depressed ammonification, the point of toxicity being somewhere between .005% and .01%. Lipman found the point of marked toxicity between 0.1% and 0.2%. Evidently in the soil used in his work the sodium sulfate did not become toxic at as low a concentration. The reaction of the soil may have governed the results. At any rate, some difference inherent in the soil must be responsible for the differences in the results.

SERIES IX.

This series was arranged to test the effect of the sodium chloride on ammonification in the presence of calcium carbonate. The results appear in table IX.

The results of this series and of the preceding are shown graphically in plate IV. It is apparent upon an examination of this plate and the table that .005% of sodium chloride was more stimulative to ammonification in the presence of the calcium carbonate than in its absence. Furthermore with all the amounts of the chloride used up to and including 0.1%, when calcium carbonate was present, a stimulation of the action of the ammonifiers was found. The increase in ammonia production became smaller as the amount of the chloride increased but evidently a larger amount than 0.1% would be required to be toxic when lime is present in the soil.

As with the other salts tested, then, these results show clearly that calcium carbonate instead of increasing toxicity decreases it

TABLE IX.—THE EFFECTS OF SODIUM CHLORIDE IN THE PRESENCE OF CALCIUM CARBONATE.

No.	Treatment	Mg N	Average
1	Check+0.6 gm CaCO_3 -----	100.40)	103.275
2	Check+0.6 gm CaCO_3 -----	106.15 (
3	0.005 gm NaCl +0.6 gm CaCO_3 -----	131.86 (
4	0.005 gm NaCl +0.6 gm CaCO_3 -----	126.80 (129.330
5	0.01 gm NaCl +0.6 gm CaCO_3 -----	125.00 (
6	0.01 gm NaCl +0.6 gm CaCO_3 -----	127.70 (
7	0.02 gm NaCl +0.6 gm CaCO_3 -----	118.20)	120.800
8	0.02 gm NaCl +0.6 gm CaCO_3 -----	123.40 (
9	0.05 gm NaCl +0.6 gm CaCO_3 -----	115.25)	
10	0.05 gm NaCl +0.6 gm CaCO_3 -----)	115.250
11	0.1 gm NaCl +0.6 gm CaCO_3 -----	103.40 (
12	0.1 gm NaCl +0.6 gm CaCO_3 -----	109.35 (

considerably and may even reverse the toxic action and bring about a beneficial or stimulative effect on ammonification.

SERIES X.

Various combinations of the salts used in the preceding series were added to the soil with calcium carbonate and the effect on ammonification determined. The results appear in table X.

Examining table X it appears in the first place that all the combinations of salts used with calcium carbonate depressed ammonification over that occurring in the presence of calcium carbonate alone. The sodium carbonate and bicarbonate together caused a very slight depression in ammonification. The carbonate alone caused a slight decrease as shown in Series III and the bicarbonate gave a slight increase as appeared in Series V. The effects of the two together were therefore little changed from that of each individually. Sodium sulfate in the amount used

TABLE X.—THE EFFECTS OF COMBINATIONS OF VARIOUS SALTS WITH CALCIUM CARBONATE.

No.	Treatment	Mg N	Average
1	Checks+0.6 CaCO ₃ -----	102.10 }	104.350
2	Checks+0.6 CaCO ₃ -----	106.60 }	
3	0.2 gm Na ₂ CO ₃ +0.1 gm NaHCO ₃ +0.6 gm CaCO ₃ -----	97.05 }	101.820
4	0.2 gm Na ₂ CO ₃ +0.1 gm NaHCO ₃ +0.6 gm CaCO ₃ -----	106.60 }	
5	0.2 gm Na ₂ CO ₃ +0.5 gm NaHCO ₃ +0.6 gm CaCO ₃ -----	86.10 }	92.225
6	0.2 gm Na ₂ CO ₃ +0.5 gm NaHCO ₃ +0.6 gm CaCO ₃ -----	98.35 }	
7	0.2 gm Na ₂ CO ₃ +0.01 gm NaCl+0.6 gm CaCO ₃ -----	84.24 }	78.420
8	0.2 gm Na ₂ CO ₃ +0.01 gm NaCl+0.6 gm CaCO ₃ -----	72.60 }	
9	0.1 gm NaHCO ₃ +0.5 gm Na ₂ SO ₄ +0.6 gm CaCO ₃ -----	82.60 }	82.600
10	0.1 gm NaHCO ₃ +0.5 gm Na ₂ SO ₄ +0.6 gm CaCO ₃ -----	lost }	
11	0.1 gm NaHCO ₃ +0.01 gm NaCl+0.6 gm CaCO ₃ -----	79.38 }	83.295
12	0.1 gm NaHCO ₃ +0.01 gm NaCl+0.6 gm CaCO ₃ -----	87.21 }	
13	0.5 gm Na ₂ SO ₄ +0.01 gm NaCl+0.6 gm CaCO ₃ -----	76.42 }	78.710
14	0.5 gm Na ₂ SO ₄ +0.01 gm NaCl+0.6 gm CaCO ₃ -----	81.00 }	
15	0.2 gm Na ₂ CO ₃ +0.1 gm NaHCO ₃ +0.5 gm Na ₂ SO ₄ +0.6 gm CaCO ₃ -----	90.18 }	93.285
16	0.2 gm Na ₂ CO ₃ +0.1 gm NaHCO ₃ +0.5 gm Na ₂ SO ₄ +0.6 gm CaCO ₃ -----	96.39 }	
17	0.2 gm Na ₂ CO ₃ +0.1 gm NaHCO ₃ +0.01 gm NaCl+0.6 gm CaCO ₃ -----	81.35 }	81.350
18	0.2 gm Na ₂ CO ₃ +0.1 gm NaHCO ₃ +0.01 gm NaCl+0.6 gm CaCO ₃ -----	lost }	
19	0.2 gm Na ₂ CO ₃ +0.5 gm Na ₂ SO ₄ +0.01 gm NaCl+0.6 gm CaCO ₃ -----	95.31 }	93.205
20	0.2 gm Na ₂ CO ₃ +0.5 gm Na ₂ SO ₄ +0.01 gm NaCl+0.6 gm CaCO ₃ -----	91.10 }	
21	0.1 gm NaHCO ₃ +0.5 gm Na ₂ SO ₄ +0.01 gm NaCl+0.6 gm CaCO ₃ -----	75.06 }	76.545
22	0.1 gm NaHCO ₃ +0.5 gm Na ₂ SO ₄ +0.01 gm NaCl+0.6 gm CaCO ₃ -----	78.03 }	
23	0.2 gm Na ₂ CO ₃ +0.1 gm NaHCO ₃ +0.01 gm NaCl+0.5 gm Na ₂ SO ₄ +0.6 gm CaCO ₃ -----	68.80 }	70.815
24	0.2 gm Na ₂ CO ₃ +0.1 gm NaHCO ₃ +0.01 gm NaCl+0.5 gm Na ₂ SO ₄ +0.6 gm CaCO ₃ -----	72.83 }	

here gave an increase in ammonification as was noted in Series VII but with the sodium carbonate a distinct decrease occurred here. The same is true of the sodium chloride. Evidently the sodium carbonate in the presence of these salts and calcium carbonate not only offset the stimulative effect each showed alone but caused a toxic action. The bicarbonate with the sulfate and with the chloride, each of which salts stimulated ammonification when used alone with calcium carbonate, brought about distinct depressions in ammonia production. The same was true for the sodium sulfate, and the chloride. Where combinations of three of the salts were used with the calcium carbonate depressions were brought about which were somewhat variable and difficult of interpretation. Where the four salts were used the largest depression found in any case was brought about.

These results, as a whole, indicate rather distinctly that various salts in combination have toxic effects which the same salts in the same concentrations do not individually possess. Larger amounts of calcium carbonate than were used in this series might reduce the toxic effects of the combinations of salts. Further experiments are necessary to test this point. It is apparent, however, that the presence of "alkali" salts in small quantities in soils along with calcium carbonate may be distinctly toxic to ammonification.

Conclusions.

These experiments as a whole lead to the following conclusions:

1. Calcium carbonate exerted a marked beneficial influence on ammonification. The greatest effect occurred with 0.3%. Up to 5.0% however, no decrease occurred.

2. The alkali salts tested were found to exert a stimulating effect when used alone at very low concentrations. A stimulation was observed with sodium carbonate at a concentration of 0.1%; for sodium bicarbonate at 0.05%; for sodium sulfate at 0.1% and for sodium chloride at 0.005%.

3. Increased additions of these salts, however, failed to stimulate the ammonifiers but on the contrary retarded their action. The point of toxicity in this soil was between 0.1% and 0.2% for sodium carbonate, between .05% and 0.1% for sodium bicarbonate, between 0.1% and 0.5% for sodium sulfate and between 0.005% and 0.01% for sodium chloride.

Increasing additions of all these salts brought about gradually increasing depressions in ammonification.

4. Calcium carbonate when used in the presence of the "alkali" salts reduced the toxicity of the salts to a considerable extent in every case. With the sodium carbonate and bicarbonate the smallest stimulative amounts of the salts were reduced by the calcium carbonate but there was no toxicity evidenced. With the sodium sulfate and sodium chloride however, the stimulative actions of small amounts of the salts were increased by the calcium carbonate. Furthermore, toxic amounts of these latter salts were not only rendered non-toxic but were made stimulative. This was particularly noticeable in the case of the sodium chloride.

5. Combinations of various salts in non-toxic individual amounts in the presence of calcium carbonate become toxic to ammonification. The greater concentrations become more toxic. Further experiments are desirable with larger amounts of calcium carbonate to ascertain whether the toxic effects of combined salts or of greater concentrations of individual salts can be removed entirely.

EXPERIMENTAL—PART II.

GREENHOUSE EXPERIMENT.

The greenhouse experiment was planned to check the work in the laboratory and test the effects of various salts in the presence and absence of calcium carbonate, on ammonification after allowing the salts to be mixed with the soil for a comparatively long period of time. It is realized that in the short incubation periods used in the laboratory tests, there was probably only a slight transformation of the calcium carbonate into the bicarbonate and hence the full effects of the use of the carbonate would not be secured. Mixing the salts with soil and maintaining at optimum moisture content under greenhouse conditions, it was believed would result after comparatively long periods of time in a more nearly natural action of the calcium carbonate. Conditions more nearly resembling those in the field would be secured by this method.

Accordingly 18 pots were each filled with the Carrington loam used in the laboratory tests.

The special treatments for each pot were as follows:

<i>Pots</i>	
1 and 2	Check
3 and 4	0.6% CaCO_3
5 and 6	0.2% Na_2CO_3
7 and 8	0.2% Na_2CO_3 + 0.6% CaCO_3

Pots	Check
9 and 10	0.1% NaHCO_3
11 and 12	0.1% NaHCO_3 +0.6% CaCO_3
13 and 14	0.5% Na_2SO_4
15 and 16	0.5% Na_2SO_4 +0.6% CaCO_3
17 and 18	0.01% NaCl +0.6% CaCO_3

After the salts were thoroughly mixed with the soil in the pots, sufficient water was added to bring the moisture content up to the optimum for the soil. Water was added to weight from time to time to keep up the moisture content.

The first sampling was made on November 26th, just six weeks after the experiment was started and the subsequent samplings were made at intervals of about two weeks.

The samples were drawn with the usual precautions to avoid contamination and ammonification tests were carried out in triplicate 100 gram portions of each soil in tumblers in the laboratory. Five grams of dried blood were added to each portion of soil and thoroughly stirred in. The moisture content was then adjusted to the optimum and the samples incubated for six days at room temperature. At the expiration of that time they were transferred to Kjeldahl flasks and the ammonia present distilled by the aeration method.

The results of these tests are given in table XI, the averages only of the triplicate determinations being given, as all the determinations proved quite satisfactory.

From table XI it will be seen that in every case calcium carbonate applied at the rate of six tons per acre gave an increase in ammonification. The amount of ammonia produced, increased with each succeeding sampling up to and including the third series. The quantity of ammonia produced at the fourth sampling was lower than that at any preceding date, finally however reaching a maximum of 209.375 mgs. at the fifth sampling.

Calcium carbonate in the amount used evidently stimulated to a considerable extent the action of the ammonifiers in this soil. These results checked those secured in the laboratory tests and also confirmed many other experiments with calcium carbonate.

The results with the sodium carbonate were somewhat variable. At the first, second and fourth samplings, a decrease in ammonification over that in the check soil was noted; while at the third and fifth samplings an increase was found. In the laboratory tests the amount of the salt used here gave a distinct depression, hence it is probable that the decreases at the three samplings represented the actual effect of the bicarbonate on ammonification.

TABLE XI—MGS N AS AMMONIA IN AMMONIFICATION TESTS.

	Treatment	1st Sampling		2nd Sampling		3rd Sampling		4th Sampling		5th Sampling	
		Average Tripl'te Deter.	Average Dupl'te Pots.	Average Tripl'te Deter.	Average Dupl'te Pots.	Average Tripl'te Deter.	Average Dupl'te Pots.	Average Tripl'te Deter.	Average Dupl'te Pots.	Average Tripl'te Deter.	Average Dupl'te Pots.
1	Check	50.464	56.376	139.739	131.151	76.46	72.575	43.25	43.615	123.86	122.730
2	Check	62.288		122.562		68.70		43.98		171.70	
3	0.4% CaCO_3	72.320	83.126	181.792	181.792	183.47	191.310	62.43	68.863	198.39	202.375
4	0.4% CaCO_3	93.946		lost		197.15		75.296		220.36	
5	0.2% Na_2CO_3	45.60	44.435	124.133	124.741	115.53	111.400	82.64	37.265	129.98	137.170
6	0.2% Na_2CO_3	43.27		125.349		106.39		41.89		144.36	
7	0.2% $\text{Na}_2\text{CO}_3 + 0.6\% \text{CaCO}_3$	78.432	78.381	160.361	165.292	181.78	179.540	57.05	56.325	215.26	208.865
8	0.2% $\text{Na}_2\text{CO}_3 + 0.6\% \text{CaCO}_3$	78.331		170.224		177.33		55.603		202.47	
9	0.1% NaHCO_3	41.140	32.501	162.600	118.256	72.95	69.885	42.167	42.638	76.67	82.485
10	0.1% NaHCO_3	61.043		133.912		65.81		43.11		88.30	
11	0.1% $\text{NaHCO}_3 + 0.6\% \text{CaCO}_3$	125.248	110.504	142.880	135.533	189.79	195.020	88.025	75.384	237.86	238.210
12	0.1% $\text{NaHCO}_3 + 0.6\% \text{CaCO}_3$	53.769		128.187		202.25		67.543		238.56	
13	0.3% Na_2SO_4	46.165	39.772	87.855	83.568	lost	68.100	32.734	31.053	124.90	130.525
14	0.5% Na_2SO_4	33.440		79.261		68.10		29.482		116.15	
15	0.5% $\text{Na}_2\text{SO}_4 + 0.6\% \text{CaCO}_3$	93.309	89.003	175.437	161.501	166.58	167.750	59.996	57.873	207.68	220.015
16	0.5% $\text{Na}_2\text{SO}_4 + 0.6\% \text{CaCO}_3$	84.613		147.744		168.02		55.751		232.35	
17	0.01% $\text{NaCl} + 0.6\% \text{CaCO}_3$	104.889	93.682	134.672	136.496	180.07	178.850	60.302	74.412	208.20	212.065
18	0.01% $\text{NaCl} + 0.6\% \text{CaCO}_3$	82.485		138.330		177.64		79.522		215.98	

The soil treated with both calcium carbonate and sodium carbonate together gave a very decided increase in ammonia production over the check and also over the sodium carbonate alone. Slightly less ammonification occurred in every case than where the calcium carbonate was used alone. Evidently the calcium carbonate not only reduced the toxicity of the sodium carbonate but also brought about an actual increase in ammonification. The increase was less however, than the calcium carbonate brought about alone. These results confirmed, almost exactly, those secured in the laboratory studies.

Sodium bicarbonate in a concentration of 0.1% gave a decrease in ammonification in every case as compared with the check. It appeared markedly toxic at the second and fifth samplings but less so at the other dates. This amount of salt proved toxic also in the laboratory tests.

The soil treated with calcium carbonate and sodium bicarbonate together showed a decided increase in ammonification, in every case, as compared with that treated with sodium bicarbonate alone. With one exception, where the variation was slight, the combination of salts caused a greater ammonification than that brought about by the calcium carbonate alone. These results confirm thoroughly those secured in the laboratory tests. Calcium carbonate not only was able to remove the toxicity of the sodium bicarbonate to a large extent but the combination proved beneficial to ammonification. In fact, a slight gain in the process was occasioned by the two salts over that brought about by the calcium carbonate alone. It would seem therefore that the sodium carbonate, toxic in the amount used, was not only made non-toxic but actually stimulative to the ammonifiers by the action of the calcium carbonate.

The presence of sodium sulfate in a concentration of 0.5% decreased ammonification at every sampling. This effect of this salt checked very well with the results secured in the laboratory tests.

When calcium carbonate was added with the sodium sulfate, the ammonifying power of the soil was increased in every case over that in the check soil and in the soil treated with the sodium sulfate alone. In two cases greater effects were secured than with the calcium carbonate alone and in the other three instances only slightly less amounts of ammonia were produced. The laboratory tests with these salts were therefore quite satisfactorily confirmed by these results.

Evidently calcium carbonate when applied with sodium sulfate in the amount used here, not only had the ability to remove

the toxicity of the sodium salt but actually made it slightly stimulative.

The sodium chloride used with calcium carbonate proved quite decidedly beneficial to ammonification. Greater increases in ammonia production were obtained at three samplings than with the calcium carbonate alone and at the other two dates the differences were slight. The amount of sodium chloride, used here, when applied alone was toxic to the ammonifiers and hence it is evident that the calcium carbonate not only removed the toxicity of the salt used but made it stimulative to ammonification. These results again checked those secured in the laboratory studies.

It is apparent from these results as a whole that toxic amounts of certain "alkali" salts were not made more toxic to ammonification by the addition of calcium carbonate. In fact, in some instances, toxicity was changed to a stimulative effect on the ammonifiers. Of course if very much larger amounts of calcium carbonate were used than those employed here, the results might be quite different. Different results would also undoubtedly be secured with smaller and larger amounts of the "alkali" salts. It must be understood therefore that the conclusions drawn are specific for the amounts of all salts used in this work.

The greenhouse experiments confirm very satisfactorily the laboratory tests and the fact stands out preeminently that calcium carbonate in soils containing "alkali" salts in certain amounts does not make them toxic but decidedly less so and may even make them stimulative on ammonification.

CONCLUSIONS.

The conclusions which may be drawn from this work are as follows:

1. Calcium carbonate applied at the rate of 0.6% proved highly stimulating to the ammonifiers.
2. Sodium carbonate, at the rate of 0.2%, sodium bicarbonate at the rate of 0.1% and sodium sulfate at the rate of 0.5% proved toxic to ammonification.
3. Calcium carbonate applied with these amounts of "alkali" salts and with 0.01% sodium chloride removed the toxicity of the salts in all cases and in some instances made the toxic amounts of salts actually stimulative to ammonification.

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